UNIVERSITY OF CALIFORNIA PUBLICATIONS.

ADDRESSES

DELIVERED AT THE DEDICATION OF THE NEW BUILDINGS AND EQUIPMENT OF THE STUDENTS' OBSERVATORY OF THE UNIVERSITY OF CALIFORNIA

JANUARY 30, 1904.

[Reprinted from *Publications of the Astronomical Society of the Pacific*, Vol. 16, No. 95.]

THE STUDENTS' OBSERVATORY, AT BERKELEY, CALIFORNIA.

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The exercises in dedication of the new buildings and equipment of the Students' Observatory were held in the Astronomical Lecture Room of the University of California on January 30, 1904, in connection with the regular January meeting of the Astronomical Society of the Pacific. After a brief address of welcome to the members of the Society by President Benjamin Ide Wheeler, of the University of California, the following addresses and papers were read:—

Introductory Remarks: W. W. Campbell.

History and Aims of the Students' Observatory: A. O. Leuschner.

The Constant of Refraction: R. T. Crawford.

The Watson Asteroids: Burt L. Newkirk.

The Photographic Equatorial of the Students' Observatory: A. F. Gillihan.

DEDICATION OF THE STUDENTS' OBSERVATORY, AT BERKELEY.

INTRODUCTORY REMARKS.

By Director W. W. Campbell.

(Before the Society at the meeting in Berkeley, January 30, 1904.)

There is probably no situation in which men and their work are more accurately judged than in a great modern university. The real and the superficial are almost unerringly sorted out by the open-minded and quick-witted students, by colleagues on the faculties, and by the conscientious and responsible heads of the institutions. The departments which seem to prosper year after year are really prosperous and are deservedly so.

One of the conspicuous features of university governments is an application of a very old truth—to the department that hath shall be given.

The addition to the Students' Observatory which we have met to dedicate this evening is an illustration of this fact. It is not to be thought of as an addition to California's list of properties; it is not simply a building containing a collection of astronomical instruments,—that would be a museum. Friends have presented the instruments, and the University has accepted, mounted, and covered them, with the expectation, based upon the record of the Department, that they will be used. They are an opportunity, and at the same time a responsibility. It is intended, I think, that they shall be employed for two main purposes: for giving instruction in the fundamental principles of the science, and for making original investigations, principally by the officers of the Department.

The elements of astronomy are taught more or less efficiently in a great number of American schools and colleges. Some of the teaching is real astronomy, and other portions are called astronomy by courtesy. The varieties differ as widely as the work of a local business college differs from that of a great metropolitan banking institution. Our colleges and universities which are successfully teaching the theory and practice of astronomy can almost be counted upon the fingers

of the two hands. Nearly all of them make specialties of certain lines of astronomical work, depending upon the experience of the men in charge; and in these lines the instruction is of a very high grade. But there is, I think, no other American university in which real astronomy is taught so extensively as in the Berkeley Astronomical Department of the University of California. Taking into account also the astrophysical work and opportunities of the Department of Physics, and the encouragement and facilities extended, by fellowships and otherwise, to especially promising students at the Lick Observatory in all lines of research prosecuted there, the astronomical advantages of the University certainly seem to be unsurpassed. It is a pleasure to note that all the men who have taken advantage of them in the past few years have secured appointments to positions which afford them at least the opportunity to make suitable returns.

There is a strong and increasing demand for well-trained men and women to fill university and observatory positions, and I trust that the Berkeley Astronomical Department will have continually growing success in starting promising students on their careers in this pure science.

It is not desirable that these new instruments should cause individual students to spend more time on their undergraduate astronomy; but, rather, that they should spend the same amount of time more efficiently, and that a greater number of students should be attracted to the study of astronomy and have their requirements suitably met. If these instruments should entice the future astronomer away from simultaneous studies in the English language and literature, in history, in economics, and in other studies which broaden and balance him, then they would in fact be a detriment. Any undergraduate training in our science secured at the sacrifice of a liberal and broad education is a failure. No matter how excellent his special training, the young astronomer starts upon his profession badly handicapped if he is not proficient in speaking and writing his own language, and if he does not possess reasonable knowledge of many subjects apparently unrelated to his science.

In these days of great things one frequently hears the opinion expressed that for useful investigational work in astron-

omy powerful telescopes are demanded. It is true that recent advances in our science have been due in large part to the possession of powerful and expensive equipment. But the directors of observatories possessing such equipment are wisely restricting their programmes of work to those problems which cannot be solved equally well with small instruments; and it would be a grievous mistake to assume that the small telescope in suitable hands is not able to render good account of itself. Reference to the work of a few small telescopes makes interesting reading:—

The observations for ARGELANDER'S Durchmusterung, the work consulted more frequently than any other by astronomers, were made with a 3-inch refractor;

The Cordoba Durchmusterung, continuing the above work to the South Pole, is based upon observations made with a 5-inch telescope;

Nearly all unexpected comets are discovered with instruments not more than six inches in diameter, and great numbers of accurate determinations of their positions are made with the same telescopes;

Remarkable contributions to our knowledge of the forms and development of comets have been made in the past twelve years almost wholly with photographic telescopes from four to six inches in diameter;

Our comprehension of the elements which contribute to success in the difficult work of measuring the motions of the stars in the line of sight has increased until to-day we should be able to prove with a 6-inch telescope and a suitable spectrograph that *Capella* is a spectroscopic binary star whose two components, of nearly equal size, revolve around their common center of mass in 104 days;

The work of Dr. ROBERTS in the past ten years, in South Africa, on the photometry of variable stars, has been remarkable for its accuracy, quantity, and systematic nature; yet it has all been done with telescopes varying in size from one to three inches;

KEELER'S spectrographic observations of the velocities in the ring system of *Saturn*, in my opinion, constitute the most beautiful individual observation made in recent times; yet his telescope, located in a region notorious for its poor atmos-

pheric conditions for such work, was only thirteen inches in diameter.

In closing this informal address, I beg to relate an incident which bears upon the question of the success of the excellent and beautifully finished new instruments which we are invited to inspect at the close of this meeting: In the year 1893, a prominent citizen of California, connected at the time with the educational system of the State, visited the Lick Observatory and inspected its instruments. I well recall his expression of disapproval when he saw that the brass tube of the Crocker telescope, with which Professor BARNARD was securing his famous photographs of the Milky Way and comets, looked worn, and did not carry the polish which one sees on the companion-rail of a steamship. And later in the day, when the star spectroscope, which Professor KEELER had used so successfully in measuring the motions of the planetary nebulæ, and in investigations on objects of special interest, was seen to be worn and scratched from five years' continual use, it was remarked, quite forcibly, that we did not seem to be taking very good care of our instruments.

The most comprehensive good wish that I can make for the Berkeley Astronomical Department, in whose success we all rejoice, is, that when the Astronomical Society of the Pacific is again invited to hold a meeting in the Students' Observatory we shall find the varnish worn away from many parts of these new instruments.

HISTORY AND AIMS OF THE STUDENTS' OBSERVATORY.*

By A. O. LEUSCHNER.

The buildings and equipment which we dedicate to-night bring us considerably nearer to the realization of the hope of having at the University of California a well-equipped Students' Observatory. Our hearts are full of gratitude to those who have helped us meet our most pressing needs.

* Address delivered before the Astronomical Society of the Pacific, January 30, 1904, at the dedication of the new observatory buildings of the University of California. Rewritten for the *Publications* of the Astronomical Society of the Pacific.

On behalf of the Berkeley Astronomical Department, I thank Mr. William M. Pierson for the gift of his splendid eight-inch reflector; Mrs. Herman Oelrichs, for the donation of the late Senator Fair's five-inch refractor; the President and the Hon. Board of Regents, for the erection of suitable buildings; and last, but not least, again, President Wheeler, who is ever taking a keen interest in all that concerns our students, for causing the regular budget of the Students' Observatory to be increased so as to enable us to make material additions to our equipment. The total value of our new possessions is over nine thousand dollars, the value of the new equipment alone being over five thousand dollars. Our thanks are also due to Professor John Galen Howard, Supervising Architect of the University, and his staff, for the care taken in meeting our requirements, with reference to the design of the new buildings, and to the California School of Mechanical Arts, particularly to Messrs. G. A. Merrill and E. T. Hewitt, for their aid in the construction of the photographic telescope and the running-gears of the new domes. Dr. A. F. Gillihan and Mr. Val. Arntzen are to be particularly complimented for the energy and efficiency displayed by them in the construction of the photographic telescope and in putting our new equipment in place.

The new buildings are intended to be temporary, and are constructed of wood. They consist of a main building, with domes for the Oelrichs and photographic telescopes, and a separate dome for the Pierson reflector. The main building extends north and south on the west slope of the hill on which the Students' Observatory is situated, and faces east. It contains, aside from the domes, two large rooms, 30 x 30 and 20 x 30, on one floor; also a photographic dark-room and store-rooms in the basement. The reflector dome is located on the south slope of the hill.

The new equipment includes the Pierson (Newtonian) reflector, of 8 inches aperture and 6 feet focal length, by Brashear; the Oelrichs refractor, of 5 inches aperture and 6⅓ feet focal length, lens by Alvan Clark and mounting by Gaertner & Co., Chicago; a mounting designed and constructed in the University for the Harrison portrait-lens, of 5½ inches aperture and 22 inches focal length, a Repsold

measuring-apparatus for measuring positions on photographic plates, and a Gaertner comparator for measuring spectrograms.

In addition to these improvements a wooden platform surrounding three piers has been erected in the open space between the old and new buildings, for use as an open-air observatory with portable instruments. The three instruments in question, which have been loaned to the department, are a 3-inch equatorial of 4 feet focal length, a 1¾-inch Browning transit-instrument, and a 1⅛-inch altazimuth instrument, with circles graduated to 5″.

Our new acquisitions are primarily intended to increase the efficiency of our instruction in practical astronomy, but they will also afford the members of the department considerable opportunity for original observation.

The Students' Observatory of the University of California occupies a unique position among the astronomical observatories in this and other countries. Founded originally for the purpose of giving a few civil-engineering students the astronomical knowledge necessary to their profession, its development ever since has been in the direction of creating new opportunities for the study of astronomy in all its branches, until now it is well recognized that the University of California, with its two astronomical departments—the Lick and the Berkeley—has a well-organized and prominent training-school for the profession of astronomy. It was through the efforts of Professor FRANK SOULÉ, head of the Department of Civil Engineering, ably assisted by Professor WILLIAM THOMAS WELKER, then Superintendent of Public Instruction, that an appropriation of ten thousand dollars for the erection of a Students' Observatory was secured from the Legislature of the year 1885. The appropriation was most wisely and economically expended, about one half being applied to the erection of the necessary building and one half to equipment.

Instruction in this little observatory commenced in the fall of 1887. I well remember the fine impression which the observatory made upon me when I first visited the same in 1889, during my career as a student in the Lick Observatory. Coming down from the great Lick Observatory, with its huge and magnificent instruments and perfect equipment, the Stu-

dents' Observatory impressed me as a neat and complete model of what a large observatory should be.

The observatory building then consisted of the dome, housing the 6-inch equatorial of 8⅓ feet focal length; the small instrument-room for minor apparatus; the transit-room, containing the 3-inch Davidson zenith and transit telescope; the Howard mean-time clock, the chronograph, and the switch-board; and two small rooms. A small house in the rear harbored the Ewing, Gray, and Duplex seismographs. The minor equipment included a spectroscope, sextants, chronometers, level-trier, and spherometer.

Since then the observatory has been enlarged four times, by the addition of a computing-room, 17 x 30; an office for the Director; a lecture-room, seating 200 students; and the buildings which are being dedicated to-night.

In the earlier days the headquarters of the Department of Civil Engineering and Astronomy, of which the Students' Observatory formed the other part, consisted of one room on the top floor of North Hall. The head of the department and one instructor made up the staff. It was not long before the burden of carrying the instruction in civil engineering as well as in astronomy became so great that Professor SOULÉ was forced to ask to be relieved of the latter, and in 1892 the courses in general and practical astronomy, offered for the benefit of the civil-engineering students, were assigned to me while I still retained my connection with the Department of Mathematics.

It was at this time that the tremendous possibilities in the University of California for the development of a successful department of instruction first impressed themselves upon me.

The ideals which since then have constantly been kept in mind were first to shape the undergraduate work in astronomy so that upon graduation the student would be found fully qualified to take part as an assistant in the regular work of a large observatory, and then to develop graduate instruction in such lines as could be satisfactorily undertaken at Berkeley. At the same time the original purpose of the observatory—to afford the necessary instruction in astronomy and geodesy to civil-engineering students—has been carefully adhered to. Provision has also been made for special instruction in navi-

gation and nautical astronomy for students in the College of Commerce. Aside from these functions of the observatory, which provide instruction for students with specific views in mind, the department has organized general lecture and observatory courses, open to all students of the University, for the benefit of those who wish to familiarize themselves with the fundamental principles of astronomical science, their philosophy and historical development. In these courses special attention is paid to modern methods of research and new discoveries. Among others, the course in modern astronomy is given jointly by the Lick and the Berkeley Astronomical Departments and every member of the University enjoys, therefore, the opportunity of being brought into immediate contact with the most recent work of our great Observatory at Mount Hamilton.

That there always has been and now is call for a thorough training-school for the astronomical professions needs hardly to be emphasized. Perhaps no science attracts the popular fancy more than astronomy. As a result many gifted men and women acquire small telescopes and devote themselves as amateurs to a certain limited class of observations, often reaching therein a perfection which places their names prominently before the world. A university should extend to them every opportunity to combine with their enthusiasm, energy, and brilliancy a profound knowledge of the necessary principles of mathematics, physics, and astronomy. Many university graduates who in their undergraduate career plan to become astronomers later find that the institutions which they have attended were not prepared to give them the necessary instruction and guidance.

The necessity of a thorough preparation for the professions of medicine, law, and engineering has long been recognized, and the energies of most universities are bent on offering the best possible preparation for them. Of the pure sciences none is so much in need of similar attention as astronomy, as it depends in an unusual degree upon allied sciences, particularly upon mathematics and physics.

The question, however, might arise whether or not the organization of a department of instruction in astronomy at Berkeley would involve a serious and undesirable duplication

of the work of the great Lick Observatory, which forms an integral part of the University. We might ask ourselves whether a university should abandon its medical instruction because it is in touch with famous hospitals. Would the hospital work be of benefit to any one but a qualified student for further experience? Is such a university not all the more under obligation to organize the best possible medical instruction, so as to give its young doctors the full benefit of the available hospital opportunities? Or would it be feasible to attempt the instruction in the various branches of science upon which medicine depends in the hospital itself? And, further, ought graduate or research work in astronomy be attempted at Berkeley? Is not the work of our new Physiological Laboratory under Professor LOEB of the highest importance to medical science? Is there not research work in astronomy which is similarly related to the observational work of a great observatory? Among others, *theoretical astronomy* and *celestial mechanics* certainly are.

The two directions in which the energies of the department at Berkeley ought to be applied, clearly defined themselves at the outset, and ever since the aim of the department has been to develop elementary and advanced instruction in all branches of astronomy, and to organize, in particular, graduate and research work in theoretical astronomy and celestial mechanics.

Thus our aims have been to supplement rather than duplicate the work of our great Observatory at Mount Hamilton. No astronomical department, however, can be of great service to intending astronomers without the hearty co-operation of other departments, particularly of mathematics and physics. It is only fitting that on this occasion acknowledgment should be made of the hearty co-operation which the heads of these departments in this University have shown at all times in providing for the needs of our astronomical students.

The first important step in the development of our so-called "School of Astronomy" was taken in 1894. when the College of Civil Engineering organized a special undergraduate course in astronomy and geodesy. With the organization of our College of Natural Sciences and the growing demand for instruction in pure astronomy, this course was taken out of the College of Civil Engineering. A few years later the Stu-

dents' Observatory was separated from the Department of Civil Engineering and Astronomy, the new department receiving the name of "Berkeley Astronomical Department."

A new impetus was given to the efficiency of the work of higher instruction in astronomy in 1898, when, at the recommendation of Director KEELER, a vacancy in the regular staff of the Lick Observatory was filled by the appointment of three graduates of the University of California to fellowships in the Lick Observatory, with the privilege of spending one term each year in graduate work at Berkeley.

When I made a suggestion in this direction to Professor KEELER on the day of his arrival in California, he expressed his doubts as to the value in a large observatory of young graduates whose sole experience consisted in the astronomical work done as undergraduates, but he agreed to try the experiment for one year. A few months later, at a meeting of the heads of departments at Berkeley, he expressed regret that more fellowships were not available for our graduates. Since then the Lick and the Berkeley astronomical departments have commenced to vie with each other in meeting the needs of graduate students.

While at first the time of Fellows at Mount Hamilton, by force of circumstances, was much taken up with ordinary routine work, Director CAMPBELL is lending his energies more and more to create for them opportunities and facilities for original research, so that it would seem that at present, through the co-operation of the various departments concerned, the organization of the instruction in astronomy and its allied subjects, particularly for candidates for the degree of Doctor of Philosophy, leaves little to be desired.

The University of California has already turned out a formidable array of young astronomers. Some of its graduates are at the head of astronomical departments in Eastern institutions. The two men who compose the staff of the Mills Expedition of the Lick Observatory to South America were first introduced to the science of astronomy in this building. One man is a research assistant in theoretical work under Professor NEWCOMB in the Carnegie Institution at Washington. Several are rapidly rising in the United States Coast and Geodetic Survey. One is instructor in this depart-

ment, and so on. Eight have been found worthy of appointment to fellowships in the Lick Observatory. In this connection, it may be stated that only students who give evidence of exceptional qualifications as accurate observers and computers, and of ability for original research, are recommended by the Berkeley Astronomical Department for admission to the Lick Observatory.

Many students of astronomy turn their eyes to California for the completion of their training. During the few weeks which have elapsed since the opening of the current semester, this department has received no less than four applications from men and women already actively engaged in astronomical work, with reference to the conditions on which they might continue their theoretical work at Berkeley, and no doubt Director CAMPBELL receives even more applications from advanced students who desire to profit by the unexcelled opportunities of the Lick Observatory.

Thus our efforts seem not to have been in vain. Not long ago, Professor NEWCOMB was reported to have stated that there were two things standing out prominently in astronomical science of to-day: on the one hand the never-ceasing flow of new and startling observational results from the Lick Observatory, and on the other the production of men, well trained for their profession, in the University of California.

It is our constant aim to turn out men who are not merely astronomical practitioners, but *scholars* in the true sense of the word. It is scholars who are needed in astronomy—men capable of promoting science.

An outline of the various courses of instruction offered to astronomical students has been printed by the University under the title "Announcement to Students" by the Lick Astronomical Department and the Berkeley Astronomical Department. It may not, however, be without interest to state here a few characteristic features of the instruction given in this department. First of all, we make it clear to students who desire to prepare for an astronomical profession that their chief reward in later life will consist in the satisfaction which they will derive from their work. Only those who prove themselves to be exceptionally well fitted for astronomical work are encouraged to continue their studies. The quality of

the students enrolled, and not numbers, count in our advanced classes. At all times a close personal contact between students and instructors is preserved, the student sharing whatever problem the instructor may be engaged upon.

In the practical courses we have no set programme of observations and reductions. A student is kept at work from the very beginning with the same instrument—generally the sextant—until he can use it with the skill of an experienced astronomer. This means slow progress at first, but our experience has taught us that the student who thoroughly masters one instrument is not satisfied until he can handle every other instrument equally well. It is in this way that the student will gradually acquire that taste for thoroughness and accuracy so characteristic of BESSEL. With the instrument which he has mastered the student takes part in such work as the observatory undertakes from time to time. Students are not taught to do approximate work first, but the greatest accuracy is aimed at from the outset. Approximate work where it is sufficient can only then be done intelligently, when the subject is first thoroughly mastered. Problems are selected which require the greatest skill. Thus by stellar distances students have determined with great accuracy the eccentricities of our sextants and have determined the longitude by lunar distances. In practice the last-named experiment has become obscure, but its training value cannot be underestimated. By the telegraphic method students have furnished the observatory with accurate determinations of the differences in longitude between Berkeley, Mount Hamilton, and San Francisco. Extended latitude series by TALCOTT's method are available for discussion; similarly, comets, asteroids, and variable stars are observed from time to time, etc.

In theoretical work the same thoroughness is aimed at. Independent thought is cultivated in students, as well as a critical attitude toward what they receive in lectures or from books. Mechanical reduction of observations without a thorough knowledge of the subject is distinctly discouraged. In the theory of orbits a comparative study is made of the various methods proposed for deriving the elements of newly discovered comets or asteroids, with a view to enable the student to select in a given case the method best suited to the solution of

the orbit on the basis of the underlying conditions. A senior, before graduation, is expected to be ready to calculate at a moment's notice a preliminary orbit and ephemeris of a newly discovered comet or asteroid.

This work has been extensively practiced in the past, and on more than one occasion students of this University were the first to announce the orbit of a new comet. By making the student participate in the real astronomical work of the day, his ambition and enthusiasm are constantly stirred.

The numerical determination of the perturbations of the Watson asteroids supplements the work in the seminary or the lecture-room.

A great part of the scientific output of the Students' Observatory must be considered to consist in the later achievements of the men who go forth from it. Owing to the large amount of time devoted to the training of students the members of the department are naturally handicapped in prosecuting their own researches. It is not uncommon for us to find ourselves called upon to drop our own investigations at a critical point, in order to assist a student in his work. Nevertheless, we have been able to publish some observations and theoretical investigations which are not without value, and several important papers are now awaiting the finishing touches for publication.

This account of the aims and the history of the Students' Observatory would not be complete without touching upon some of the wants still felt. Aside from the new observatory which is to form part of the Greater University under the PHŒBE HEARST plans, this department needs above all the establishment of some scholarships or fellowships.

I trust that the members of the Astronomical Society of the Pacific, whom we so gladly welcome here to-night, and who I hope will be seen frequently in these buildings hereafter, will aid us in our ambitions. Perhaps some day they may wish to make their headquarters on these grounds, thus benefiting themselves and us by closer contact with one another.

THE CONSTANT OF REFRACTION.

By Russell Tracy Crawford.

(Read before the meeting of the Society held in Berkeley, January 30, 1904.)

The phenomenon known as refraction was first mentioned by and probably discovered by Ptolemy, who lived about the second century A. D. In his famous treatise on optics he points out that the light coming to us from a star or heavenly body, on entering our atmosphere and traversing it to its lower and denser portions, is gradually bent or *refracted,* the result being that the object appears to the observer to be nearer the zenith than it actually is. He shows further that this bending ranges from zero at the zenith to a maximum at the horizon.

Walther, who worked in the fifteenth century A. D., was the first one to make any successful attempt to allow for atmospheric refraction in reducing observations.

Tycho, who is celebrated for his wonderful series of accurate observations, recognized fully the importance of refraction, and consequently made a series of observations to find out the amount of displacement of an object, due to this bending for different parts of the sky, and constructed the first table of refraction. Although it was not a very accurate one, it marks an epoch in the study of this phenomenon. Kepler, following Tycho, made a considerable improvement in the theory of astronomical refraction.

The law of refraction was discovered by Snell in the early part of the seventeenth century. In the latter part of this same century, Cassini computed a new table of refractions which was an improvement upon Kepler's. This was, in turn, followed by a further improvement by Bradley in the early part of the eighteenth century.

About 1818 Bessel gave us his theory of refraction, which is the one used to-day. "Although the complete theoretical solution was then, as now, unattainable, he succeeded in constructing a table of refractions which agreed very closely with observations, and was presented in such a form that the necessary correction for a star in almost any position could be obtained with very little trouble."

The importance of refraction in any problem involving, either directly or indirectly, the zenith distance of an object is evident. The amount of the bending depends upon two things, the density of the air surrounding the observer, and the angle at which the ray of light strikes the refracting medium. As for the variation with the angle of incidence, we may say that refraction varies (very nearly) directly as the tangent of the angle of incidence. The density of the air depends principally upon the elevation above sea-level, and the temperature. BESSEL's theory takes account of all these things, and in this theory is involved what is known as the constant of refraction.

We might now ask what we mean by the constant of refraction, or what is the constant of refraction. It is *not* a number representing something of which we can form a definite picture, as we can of the constant of aberration, for instance, which is the angle whose tangent is the ratio of the velocity of the Earth in its orbit to the velocity of light; but it is one of two numbers which enter as constants into the general expression of refraction, and cannot be described in words, but merely represented analytically. These two constants are usually designated α and β; but the one called α is known as *the* constant of refraction.

The values of these constants may be found from theory by making some assumption as to the law of the decrease of density of the air for increasing heights above the surface of the Earth. Several such assumptions have been made and tables of refraction deduced from them; some of them give values of the refraction which agree fairly well with observations for a short distance from the zenith, but fail utterly for large zenith distances. The hypothesis presented by BESSEL, however, holds very well indeed for all zenith distances down to about 85°. It is upon this hypothesis that modern refraction tables are based.

First, then, tables were made from these theoretical values of the constants, and corrections have since been made to them by making use of the discrepancies found to exist between the theoretical values of the refractions and the actually observed values. These discrepancies are small; so small, in fact, that we may regard the formula for refraction, which in-

volves these constants, as representing the *law of refraction* well enough, but they are too large to give very fine results, such as are needed in work with the meridian-circle. The constants of refraction, therefore, must receive small corrections in order to make theory and observation harmonize. The constant β is small, and is undoubtedly very accurately known, so that our attention, for the present, will be directed wholly to *the* constant of refraction, α.

Considering, then, that no correction to β is needed, the following equation can be shown to exist:—

$$dr = \frac{r}{\alpha} d\alpha$$

in which r is the refraction, α the constant, dr the difference between the observed and the computed refraction, and $d\alpha$ the small correction to be applied to the constant, upon which the computed refraction depends, to obtain the constant which will agree with the observations.

The whole problem, therefore, resolves itself into finding some means of deriving the true refractions from observations so that we may form the quantity dr. There are several methods of obtaining refractions from observations. The one generally used, and which gives excellent results, is by observations of circumpolar stars. I shall explain this method in the words of YOUNG, taken from his General Astronomy:—

"At an observatory whose latitude exceeds 45° select some star which passes through the zenith at upper culmination. It will not be affected by refraction at the zenith, while at the lower culmination, twelve hours later, it will. With the meridian-circle observe its polar distance in both positions, determining the 'polar point' of the circle in the usual way. If the polar point were not itself affected by refraction, the simple difference between the two results for the star's polar distance, obtained from the upper and lower observations, would be the refraction for the lower point.

"As a *first approximation*, however, we may neglect the refraction at the pole, and thus obtain a *first* approximate lower refraction. By means of this we may compute an *approximate* polar refraction, and so get a first 'corrected polar point.' With this compute a second approximate lower refraction, which will be much more nearly right than the first; this will give a second 'corrected polar point'; this will in turn give us a third approximation to the refraction; and so on. But it would never be necessary to go beyond the third, as the approximation is very rapid. If the star does not go exactly through the zenith, it is only necessary to compute each time approximate refractions for its upper observation, as well as for the polar point."

This method, as I have said, gives excellent results, but it has several disadvantages, which it might be well to note. In the first place, it is easily seen that the computations required are quite complicated because of the approximations which have to be made; further, the latitude and its variation are involved; again, the field of observation is limited; and finally, there must be a wait of twelve hours or six months between the observations at upper and lower culminations. If this wait is twelve hours, one observation, in general, will be made in the daytime under entirely different atmospheric conditions from the one made at night; if the wait is six months, so that both observations may be made at night, the atmospheric conditions will again probably be entirely different at the times of the two observations.

It is my purpose now to present briefly another method by which refractions may be observed. It may be stated as being a "quasi" converse to TALCOTT's method of determining latitude. Instead of eliminating refractions to get the latitude the method is to determine the refractions by eliminating the latitude, as follows:—

Let $z_s =$ the zenith distance of a southern star.
$z_n =$ the zenith distance of a northern star.
$z'_s =$ the apparent zenith distance of the southern star.
$z'_n =$ the apparent zenith distance of the northern star.
$\delta_s =$ the declination of the southern star.
$\delta_n =$ the declination of the northern star.
$r_s =$ the refraction of the southern star.
$r_n =$ the refraction of the northern star.
$\phi =$ the latitude of the meridian-circle.

Then
$$\delta_n = \phi + z_n = \phi + (z'_n + r_n) \quad (1)$$
$$\delta_s = \phi - z_s = \phi - (z'_s + r_s) \quad (2)$$
$$\delta_n - \delta_s = z'_s + z'_n + r_s + r_n \quad (3)$$
Let
$$A = \delta_n - \delta_s \quad (4)$$
$$B = z'_s + z'_n \quad (5)$$
Then
$$A = B + r_s + r_n \quad (6)$$
or
$$r_s + r_n = A - B \quad (7)$$

If now the southern and northern zenith distances were the same, and if, at the times of observing them, the condi-

tions of the atmosphere were the same, the two refractions would be the same,—i. e.—

$$r_s = r_n$$

In this case we have

$$2r = A - B \tag{I}$$

In practice these ideal conditions are only approximately satisfied. We therefore proceed as follows:—

From (7) we have

$$2r_s - r_s + r_n = A - B \tag{8}$$

whence $$2r_s = (A - B) + (r_s - r_n)$$

and $$\left.\begin{aligned} r_s &= \tfrac{1}{2}(A - B) + \tfrac{1}{2}(r_s - r_n) \\ r_n &= \tfrac{1}{2}(A - B) + \tfrac{1}{2}(r_n - r_s) \end{aligned}\right\} \tag{II}$$
also

In case the northern star is at lower culmination we shall have:

$$\delta_n = 180^\circ - z_n - \phi \tag{9}$$

$$\delta_s = \phi - z_s \tag{10}$$

$$\delta_n + \delta_s = 180^\circ - z_n - z_s \tag{11}$$

$$= 180^\circ - [z'_n + r_n + z'_s + r_s] \tag{12}$$

Hence $$r_n + r_s = 180^\circ - [z'_n + z'_s] - [\delta_n + \delta_s] \tag{13}$$

and $$2r_s = 180^\circ - [z'_n + z'_s] - [\delta_n + \delta_s] + [r_s - r_n] \tag{14}$$

Calling $$A' = \delta_n + \delta_s \tag{15}$$

and since $$B = z'_s + z'_n \tag{5}$$

we have

and $$\left.\begin{aligned} r_s &= 90^\circ - \tfrac{1}{2}[A' + B] + \tfrac{1}{2}[r_s - r_n] \\ r_n &= 90^\circ - \tfrac{1}{2}[A' + B] + \tfrac{1}{2}[r_n - r_s] \end{aligned}\right\} \tag{III}$$

In order to obtain the refractions from (II) and (III) it is necessary to know the declinations of the stars, their apparent zenith distances (or, rather, the sums of the zenith distances of the pairs of north and south stars), and the differences between the refractions of the pairs.

Observations were made at the Lick Observatory by myself, in accordance with this method during a few months of 1899. The stars used were all fundamental, and in a first approximation their declinations are to be considered absolute. They were taken from Professor NEWCOMB'S "Catalogue of

Fundamental Stars for 1875 and 1900, Reduced to an Absolute System." The apparent zenith distances, or the sums of the zenith distances of the several pairs, are obtained from the meridian-circle observations; and the differences in the refractions are found by computing the refractions from some standard table. In this work the Pulkowa tables have been used. The term $\frac{1}{2}(r_s - r_n)$ being of the nature of a differential refraction, any error in the constant of refraction of the table used will have practically no effect upon this difference. The more nearly ideal conditions (i. e. when $r_s = r_n$) are approached, of course, the better the determination of the refractions will be.

This method has both its advantages and its disadvantages. Among the former, the most important are: First, the total elimination of the latitude, and hence also of its variation; second, the elimination of the nadir, since $(z'_s + z'_n)$ is nothing more nor less than the difference between the circle-readings, and is therefore independent of the zenith point; third, there is no wait of twelve hours or of six months in order to observe a star at both culminations, as is usually done; and fourth, the simplicity of the reductions.

The greatest disadvantage in this method lies in the fact that the declinations of the stars have to be considered known. But by taking fundamental stars, such as those whose places are given by Professor NEWCOMB'S new Fundamental Catalogue, and by taking a large number of these stars, this difficulty will be nearly completely eliminated.

The value of the constant found from these observations, reduced by the method just given, is somewhat smaller than that used in the Pulkowa refraction tables. It is 60".159 for a pressure of 760^{mm} at 0° and 0° (C.) temperature.

For the sake of comparison, the most important determinations of the constant of refraction are given below. These values are for the conditions $B = 760^{mm}$ at 0° C. and external thermometer = 0° C. (These values are taken from Professor BAUSCHINGER'S "Untersuchungen über die Astronomische Refraction u. s. w.").

1. Fund. Astr.	60".320
2. Tab. Reg.	.440
3. Tab. Pulk.	.268

4. Fuss.	.122
5. Greenw. 1857-1865	.120
6. Pulk. 1865	.209
7. Greenw. 1877-1886	.192
8. Pulk. 1885	.058
9. München	.104

The first and second of these are determinations by BESSEL; the third by GYLDÉN; the fifth, by STONE; the sixth, by NYRÉN; the seventh, by NEWCOMB; the eighth, by NYRÉN; and the last, by BAUSCHINGER.

BAUSCHINGER gives weight zero to each of BESSEL's determinations; to the first because there was considerable uncertainty in BRADLEY's meteorological instruments; to the second, because of the uncertainty in reading the meridian-circle (read by vernier to one second). He gives equal weight to the last seven, and gets for a mean

$$\alpha = 60''.153$$

The *apparently* fine agreement of my value with this mean, however, is purely accidental, as can be seen from some further reductions of the observations which were made later. It was noticed that the value of $d\alpha$ derived from individual pairs of stars was a function of the zenith distance of the pair used. Upon plotting these values, using the zenith distance z for abscissa, and $d \log \alpha$ for ordinate, it was easily seen that these values varied quite uniformly with the zenith distance. Therefore, a term depending upon the zenith distance was introduced and the resulting equations solved by the method of least squares. This solution led to the conclusion that the so-called constant of refraction used in the Pulkowa tables needs not only a correction, but a correction for every zenith distance. In other words, the formula from which refractions are computed needs to be modified. Or the formula may be retained unaltered, and the desired agreement between observation and computation may be obtained by correcting the tables used (Pulkowa) not by a constant amount but by a variable one represented in magnitude by the expression

$$\Delta \log \alpha = 0.000101 \; [56° \; 38'.8 - z]$$

where z is the zenith distance.

THE WATSON ASTEROIDS.

By Burt L. Newkirk.

(Read at the meeting of the Society held in Berkeley January 30, 1904.)

James C. Watson was born in the province of Ontario, Canada, January 28, 1838. He graduated at the University of Michigan in 1857, and became Professor of Astronomy and Director of the Observatory of that institution six years later. He was one of our most prominent astronomers, having written a book on theoretical astronomy which is still very widely used in the United States. He died in 1880, at the age of forty-two years. During the course of his scientific career he discovered twenty-two asteroids, and at his death left a sum of money as an endowment fund, the income from which should be used to pay for certain investigations and computations which it is necessary to make in order that these asteroids may not be lost to the scientific world.

Beside the well-known greater planets the Sun's system contains a host of very minute planets called asteroids. They revolve about the Sun in the space between the orbits of *Mars* and *Jupiter*. The first one of these to be discovered was found upon the first night of the nineteenth century, the night of January 1, 1801. This is the asteroid *Ceres*, and it is the brightest, and presumably the largest, of the group, having a diameter of 600 miles. Since the introduction of photographic methods in the search for these bodies, their discovery has been made comparatively easy, and something over five hundred of them have already been found, every year adding twenty or thirty to the list. At the time of Watson's death, in 1880, less than two hundred had been found. The smallest of these bodies are probably nothing more than great rocks, ten or fifteen miles in diameter. Smaller asteroids than these undoubtedly exist, but are so excessively faint as to elude discovery.

Of all the planets of the Sun's system these asteroids offer the greatest difficulties in the matter of the investigation of their orbits. We say, roughly speaking, that the planets move about the Sun in elliptical orbits; but, more accurately speaking, none of the bodies composing the Sun's system move in

ellipses. According to NEWTON's law of gravitation, every particle of matter attracts every other particle. If the Sun were attended by one planet only, this planet would move in an ellipse, but since each planet is attracted not only by the Sun, but also by all the other planets, its path is a curve of corresponding complexity. Since the Sun's attraction is generally by far the most powerful of all the forces acting upon any one planet, it is convenient to think of the actual orbit described by a planet as a "disturbed ellipse," as we express it. We picture to ourselves an ellipse which nearly coincides with the actual orbit, and in which the planet would move if the attractive forces of the other planets should at some particular instant cease to operate. The departure of the true orbit from this assumed ellipse, due to the disturbing action of the other planets is called the perturbation of the planet under consideration. The only reason for taking an ellipse as a starting-point in the discussion is one of convenience. A circle, which is a simpler curve from a mathematical point of view, might answer the purpose in some cases better than an ellipse, and for other purposes it is advantageous to take as a starting-point a curve of greater complexity. I refer to the "peripleg-matic" curves used by GYLDÉN, which represent the path of the planet throughout a long period of years much better than any ellipse could, but seem to possess no advantages in tracing the planet's motion for a short period of time. It is a comparatively simple matter to compute an elliptic orbit, but to investigate the deviations from this orbit—i. e. the perturbations of a planet—is a task requiring in some cases a tremendous amount of labor and study.

The mathematical difficulties of the problem are such that no general method can be employed for computing the orbits of all the planets. Each planet must be treated with reference to the special difficulties which it presents, and this necessitates an intelligent and discriminating study of the various methods used in investigations of this nature, their advantages and their limitations.

The method employed in any particular case must not only be mathematically correct, but it must also be capable of yielding the desired results with the required degree of accuracy and with a minimum of numerical computation. The method

of most general application is one developed by HANSEN, and modified by HILL, NEWCOMB, and others. Newer methods which possess special advantages in certain cases have been developed by GYLDÉN, BOHLIN, and BRENDEL. These latter methods are, however, comparatively untried, and it has been found necessary here in the asteroid work at Berkeley to revise BOHLIN'S method to some extent, before employing the formulæ given. Upon opening correspondence with BOHLIN, whose method has been used on some asteroids here, Professor LEUSCHNER found that BOHLIN himself had arrived at the same conclusion and was at work upon a revision of his theory.

In the case of the asteroids the problem presents special difficulties because of the proximity of *Jupiter,* which is the largest planet, and exerts a very powerful disturbing force. In most cases, in fact, unless a high degree of accuracy is required, the effect of all the other planets combined is a negligible quantity as compared with the perturbations produced by *Jupiter.* Difficult as the problem is, it is however absolutely necessary to compute the perturbations if we would keep the asteroids from retiring again into the oblivion from which their discoverers drew them. It is not possible to predict the motion of an asteroid ten or fifteen years in advance with sufficient accuracy to permit of its being found again at the end of that time without serious difficulty unless this work is done.

In the light of these remarks, Professor WATSON'S object in endowing the twenty-two asteroids discovered by himself will be clear. If their perturbations are not derived, his asteroids will be lost to the world in a few years, but, thanks to the fund he has bequeathed for this purpose, it will be possible to predict their motion for fifty or seventy-five years in advance with sufficient accuracy to enable astronomers of the future to find them again when they are wanted without serious difficulty. One of the twenty-two must be excepted from this statement. The asteroid *Aethra,* whose original path passed close to that of *Mars,* has suffered such violent perturbation that the form of its orbit has been greatly changed, and it has not been identified since, in spite of the diligent search which has been made for it. The tracing of the motion of this planet by means of a special mathematical discussion, which will be an exceedingly difficult matter, is to be undertaken by

Miss HOBE, who is now engaged with me upon the perturbations of the other asteroids, under the direction of Professor LEUSCHNER.

Since Professor WATSON'S death, in 1880, the trustees have been trying to carry out the desire expressed in his will, by preparing tables by means of which the motion of these asteroids can be predicted for, say, fifty years in advance, with sufficient accuracy to permit of their being readily found. Up to two years and a half ago, when the work was undertaken by this department, considerable had been done, but little was ready for publication. Since that time the perturbations of ten planets have been computed here in Berkeley, and those of two more are nearing completion. Five others are to be treated by BOHLIN'S method, the work on these being already under way: the four remaining asteroids have been made the subject of investigation by other astronomers in Europe and America.

Perhaps the most important result of the investigations of the orbits of the Watson asteroids is the light thrown upon the whole subject of asteroid orbits and the methods best adapted to the various cases that arise. The treatment of twenty-two asteroids yields data which will be very valuable in the solution of one of the great problems which now confronts mathematical astronomy,—namely, that of providing tables by means of which the position of any one of the known asteroids may be found without excessive labor.

Before our tables for finding the planets in future years can be finished it will be necessary to compare the results of our investigations with observations. It is possible by this means greatly to improve the results of the numerical work. For this purpose the photographic telescope and Repsold measuring apparatus will be available. With the help of these instruments we shall be able to observe the positions of the asteroids, and a comparison of observations with theory will lead to a final improvement of the tables before publishing them.

The Watson trustees have, as may be imagined from the long time that has elapsed since Professor WATSON'S death without the completion of the task, had great difficulty in getting the work done satisfactorily. They have, however, been very well pleased with the progress made here by Drs. CRAW-

FORD and ROSS, under the supervision of Professor LEUSCHNER, and have now turned the whole work over to the latter to be completed and prepared for publication. The work is being carried on under the auspices of the National Academy of Sciences, and the present Watson trustees are: Professor SIMON NEWCOMB (chairman), Professor LEWIS BOSS, and Professor W. L. ELKIN. It is their intention to have all the results published in due time. It has, however, seemed fitting upon this occasion to offer to those interested in the Berkeley Astronomical Department this brief statement of our connection with the undertaking.

THE PHOTOGRAPHIC EQUATORIAL OF THE STUDENTS' OBSERVATORY.

By ALLEN F. GILLIHAN.

(Read before the meeting of the Society, held in Berkeley, January 30, 1904.)

It has been demonstrated by Professors BARNARD, WOLF, and others, that lenses of the portrait type, and of large aperture, on account of their great light-grasping power, are very suitable for obtaining, with long exposures, photographs of very faint stars. Such a lens has been in the possession of the Students' Observatory for some years, but for lack of a suitable mounting, little work could be done with it. From time to time, however, it has been strapped to the tube of the 6-inch equatorial, together with its wooden camera, but as, until recently, the driving clock of this instrument did not perform well, and as there was no slow motion in hour-angle, this mounting was entirely unsuitable for photographic purposes. The need for a suitable mounting was thus greatly felt, particularly so in connection with the department's work on the Watson asteroids,, it being the intention to verify by photographic observations their computed positions before tables for these asteroids are constructed.

Correspondence with various instrument-makers developed the fact that a mounting such as was desired could be constructed only at a greater loss of time and cost than seemed desirable. The department, therefore, decided to attempt the construction of a suitable equatorial mounting here in Ber-

keley, and after some study of various mountings the regular Fraunhofer model was selected.

In designing the instrument the special purpose for which it was to be used was kept constantly in mind, the object being to construct an instrument of the utmost efficiency for photographing with short-focus lenses, with a powerful and accurate driving-clock, efficient slow motion in hour-angle to control the clock, with all necessary adjustments to facilitate guiding in the dark, and with simplicity and solidity of mounting. It was also necessary to keep the cost at a minimum.

The design of our 6-inch equatorial being both simple and substantial, was used as a model, objectionable features being eliminated and necessary improvements added. One of the special features of the photographic equatorial is, that the frame has been made very compact and heavy, and in as few parts as possible. The clock has been put in a case with glass doors, situated between the equatorial head and the cast-iron column, where it will be protected from dust and moisture. The case needs to be opened only to regulate the pendulum or to oil the clock, but not to wind it. The starting and stopping mechanism is controlled from the outside of the case by means of a button on the north side of the pier. Considerable expense was saved by using commercial gear-wheels in the clock. The teeth of these wheels appear to be very evenly spaced, but the central hole in each wheel had to be recut, as every one was eccentric.

The governor is YOUNG's double pendulum, which is much used in modern instruments on account of its sensitiveness, even action, and freedom from variations due to changes in temperature or to moisture. An important feature in the clock is, that it requires about forty-five to fifty pounds' weight on the drum to make the governor revolve at the proper speed when it is not connected with the instrument; while with the governor removed and the clock connected with the instrument, it requires only about five or six pounds to drive the instrument; that is, the ratio of the weight required to drive the governor to the weight required to drive the instrument is about as seven or eight to one. When, therefore, an extra camera or other weight is added to the instrument, it will make very little, if any, difference in the speed of the governor. The

clock is provided with maintaining power, and under the present arrangement will run for over three hours with one winding.

Another important part is the worm and worm-wheel, which were cut in the Mechanical Department of the University, the worm-wheel having 480 teeth, and the worm revolving once in three minutes. Mr. G. W. Ritchie, in the *Astrophysical Journal* for November, 1901, in describing the photographic reflector constructed at the Yerkes Observatory, stated that after the instrument was assembled the worm and worm-wheel were ground together with emery flour and oil for a period of 200 hours, and afterwards polished. To this he ascribes the smooth running of the instrument. In our instrument the worm was connected by pulleys and belting directly with the driving-shaft in the workshop in such a way that when the shaft was revolving the worm-wheel, which under the influence of the driving-clock would revolve once in twenty-four hours, was made to revolve in forty-five seconds. The wheel and worm were ground together, using emery flour and oil, for nearly thirty-three hours, making over 2,600 revolutions of the worm-wheel, which at ordinary speed would be equal to about seven years' continuous running. The oil and emery were then removed, and the wheel and worm were polished, running at the same speed, using oil and rouge, for over four hours, which is equivalent to 340 turns, or nearly one year, of continuous running. In this way any irregularities were ground out, and the worm was firmly seated in the worm-wheel, where it is held in close contact by means of a strong adjustable steel spring.

The slow motion in hour-angle is introduced between the driving-clock and the worm. It is a differential gear or mouse control worked by an endless cord in the hand of the observer. Tangent-screw hour-angle slow motion brought to the eye-end of the instrument by gears is expensive, and besides has limited range; the observer is very liable to jar the instrument in moving the handle. None of these disadvantages prevail with the mouse control; while guiding the observer need not touch the instrument, except in case of a comet moving rapidly in declination. In this event, however, very accurate driving is not essential.

Clamp in hour-angle, clamp and slow motion in declination, are brought to the eye-end as in other instruments. Both slow motions are made particularly delicate, for use with a high-power eye-piece. Four feet six inches of the hour-angle slow-motion cord moves the instrument through one minute of time, and one turn of the declination slow-motion handle corresponds to four minutes in declination.

The declination-sleeve has been made unusually long, and with the circle partly counterbalances the telescope and cameras. The circles have white figures on black background, being easier to read in the dark than black figures on a white ground. The declination-circle is graduated to 30′ and reads by verniers to 2′. The hour-circle is graduated to 4^m and reads by verniers to 20^s. These graduations are fine enough for setting purposes.

A flat iron bed-plate 1 ft. x 2 ft. takes the place of the usual saddle on the end of the declination-axis to which the telescope is fastened. On it a wooden platform 2 ft. x 3 ft. is firmly fastened. The guiding telescope, a 3½-inch Mogey refractor, is fastened to one side of the under surface of this wooden platform, and a balance weight is fastened to the other side. This leaves the upper surface free for screwing on one or more cameras. This platform is a temporary expedient for the purpose of testing various cameras; later the cameras will be fastened directly to the bed-plate.

The polar-axis bearings are conical, and the weight is taken off the upper bearing by a pair of counter friction-wheels suspended in a frame-work which is pulled up by a strong adjustable steel spring. The end-thrust of the polar axis is taken up by an adjustable ball-bearing at the lower end. All those parts of the instrument that may wear or work loose are adjustable, so that lost motion may always be prevented. For example, in the declination slow motion provision is made for taking up lost motion in three directions, so that this very important adjustment can never wear loose.

A few words regarding the photographic lens: it is a C. C. Harrison portrait combination of about 5½ inches aperture and about 22 inches equivalent focus. The camera carries a 6½ x 8½ plate, but the field of view, where the star disks are quite sharp, is limited to about 10 centimeters square,

or about 10° square. An exposure of about twenty minutes on a good night will give impressions of stars of about 11th or 12th magnitude and good measurable images of 10th magnitude stars. As an example of the work possible with this lens, on December 29, 1902, with the camera strapped on the 6-inch equatorial, an exposure was made for $1^h\ 13^m$ of the region around asteroid (385) 10.1 magnitude, and a distinct trail was found very near the computed position of the asteroid.

A description of the photographic equatorial would not be complete without mentioning those connected with its construction. The heavy castings and their patterns were made by the California School of Mechanical Arts; the heavy machine work is by the J. A. Gray Machine Co.; the composition castings are by the Eureka Foundry; and the circles were graduated by the A. Lietz Co.; all of San Francisco. All other parts of the instrument were constructed by Mr. VALDEMAR ARNTZEN, of the Department of Civil Engineering. He has done all of the finer instrumental work, and also helped in solving several knotty problems in the designing.

No work has been done as yet with this instrument; but it is hoped that it will be possible in the near future to present to the Society a satisfactory report of its work.